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AN ATTEMPT TO FORECAST THE INTENSITY OF NOCTURNAL FALL MIGRATION

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SUMMARY

A method to predict the intensity of nocturnal fall migration over the area around Canadian Forces Base Cold Lake, Alberta (54°24'N latitude, 110°17'W longitude) using the local weather forecast is described.

Predicted wind direction at ground level, 3,000 feet and 5,000 feet, pressure tendency, sky cover and precipitation were used to make daily forecasts of the hourly intensity of migration for the period 1900-0500 hours MST, from September 16 through October 16, 1968.

The same method was later used to make "postpredictions", i.e., migration forecasts based on actual rather than forecast weather.

Predicted intensities of bird movement were checked against the intensities obtained from radar film.

Radar data were available for only 62 hours (38 per cent) in September and 86 hours (52 per cent) in October of a possible 165 hours each period. For these hours the accuracy (according to described criteria) of forecasts and postpredictions was 63 per cent and 77 per cent, respectively, for September and 76 per cent and 92 per cent, respectively, for October.

RESUME

On décrit une méthode permettant de prévoir l'intensité des migrations nocturnes en automne au-dessus de la base des Forces aériennes canadiennes à Cold Lake, dans l'Alberta (54°24' de latitude nord, 110°17' de longitude ouest) à l'aide de la prévision météorologique locale.

La direction des vents prévus au sol, à 3,000 pieds et à 5,000 pieds, la variation de pression, l'étendue couverte du ciel et les précipitations ont été utilisées pour faire des prévisions journalières, d'heure en heure, de l'intensité des migrations entre 19 heures et 05 heures du matin (heure locale), entre le 16 septembre et le 16 octobre 1968.

Le même méthode a été utilisée plus tard pour établir des "post-prévisions", c'est-à-dire des prévisions des migrations en se basant sur le temps du moment plutôt que sur la prévision météorologique.

Les intensités des migrations ont été comparées à celles qui ont été obtenues au radar.

On n'a disposé des renseignements donnés par le radar que pendant 62 heures (38 pour cent du temps) en septembre et 86 heures (52 pour cent du temps) en octobre sur un nombre total d'heures possibles de 165 pendant chaque période. La précision de ces prévisions et de ces post-prévisions a été de 63 pour cent et de 77 pour cent respectivement, pour septembre et de 76 pour cent et de 92 pour cent respectivement, pour octobre.

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INTRODUCTION

The aim of Operation Bird Track is to develop a system for forecasting the intensity of bird migration. This project, initiated and supervised by Dr. W.W.H. Gunn, is carried out on behalf of the Associate Committee on Bird Hazards to Aircraft of the National Research Council of Canada.

This paper presents previously unpublished work and describes a method for forecasting the intensity of nocturnal fall migration over the area around Cold Lake, Alberta. It discusses the results obtained during the test period, 16 September to 16 October 1968.

PREVIOUS WORK

The influence of weather on bird migration has long been recognized. Bagg, Gunn et al. (1950) reviewed the literature on this subject and developed a working hypothesis for the analysis and prediction of spring migration flights. The field data that they collected in eastern North America supported their hypothesis that spring migrants fly the pressure patterns, i.e., they fly with tail winds or, in terms of fronts, they fly in large numbers "during the interval between the passage of a warm front ... and the subsequent arrival of a cold front".

(a) Radar Studies at Cold Lake

On request from the Royal Canadian Air Force (RCAF), a study was initiated in 1965 at Canadian Forces Base (CFB) Cold Lake, Alberta (54°24'Nx 110°17'W), to develop a system for forecasting the intensity of bird migration.

Detailed weather data were obtained from the Base Meteorological Office. Migration data were obtained by taking time lapse movies of the Plan Position Indicator (PPI) scope (range 85 miles) of a 23-cm. surveillance radar located 2 miles NE of CFB Cold Lake. The radar films were assessed according to a code described by Fryers (1966). This code was later revised by Richardson (1966 a). The radar films showed that, even in the migration season, bird movements of different intensities may occur simultaneously in different directions. These movements are called "events" by Richardson (op. cit.).

According to the original code the combined intensity of all events, regardless of direction, is determined from the total of all bird echoes on the scope. In the revised code the intensity of each event is separately recorded. Both the intensity of an event and the overall intensity can vary from 0 to 8 according to an arbitrary scale (Richardson, op. cit.).

The results of the assessment (original code) of films, taken during September and October 1966, are given in Figures 1 and 2. They show: (a) most migration takes place during the hours of darkness, (b) nocturnal migration is heavier in September than in October, (c) maximum intensities may occur before midnight (e.g., 17-18 September), around midnight (25-26 September), or after midnight (9-10 September), (d) intensities can have a brief peak, lasting only one hour (e.g., 7-8 September), or an extended peak that lasts for several hours (e.g., 12-13 September), (e) a high intensity can be gradually built up (e.g., 14-15 October), or develop suddenly (e.g., 14-15 September).

(b) Correlations between weather and intensity of fall nocturnal migratio over the Cold Lake area were studied by Richardson and Gunn (in press

When making migration forecasts during fall 1968 I used Richardson's earlier, unpublished results (pers. comm.). The more detailed statistical analysis (Richardson and Gunn, op. cit.) later confirmed the main correlations and slightly modified some of the less obvious correlations.

Richardson (pers. comm.) found that normal migration in fall over Col Lake is southeasterly, reverse migration is northwesterly, while very few events take place in northeasterly and southwesterly directions. He analyzed events in

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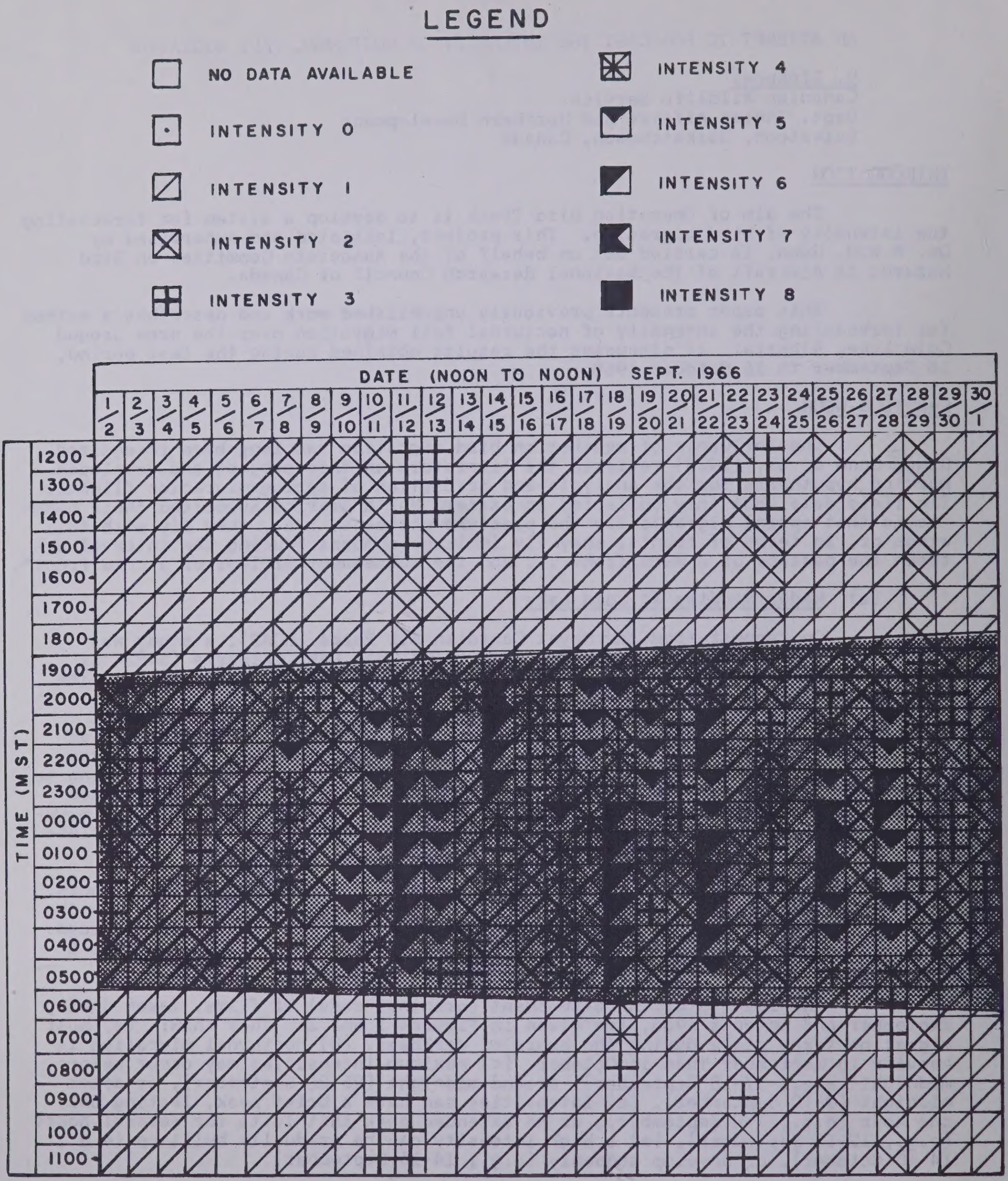


FIG. I

HOURLY INTENSITIES OF MIGRATION OVER CFB COLD LAKE, ALBERTA, AND ITS SURROUNDING AREA (RADIUS 85 MILES) DURING SEPTEMBER 1966. DATA WERE OBTAINED FROM RADAR FILM, ASSESSED ACCORDING TO FRYERS' (1966) CODE. INTENSITIES WERE DETERMINED ON THE HOUR. SHADED AREA INDICATES PERIOD BETWEEN SUNSET AND SUNRISE.

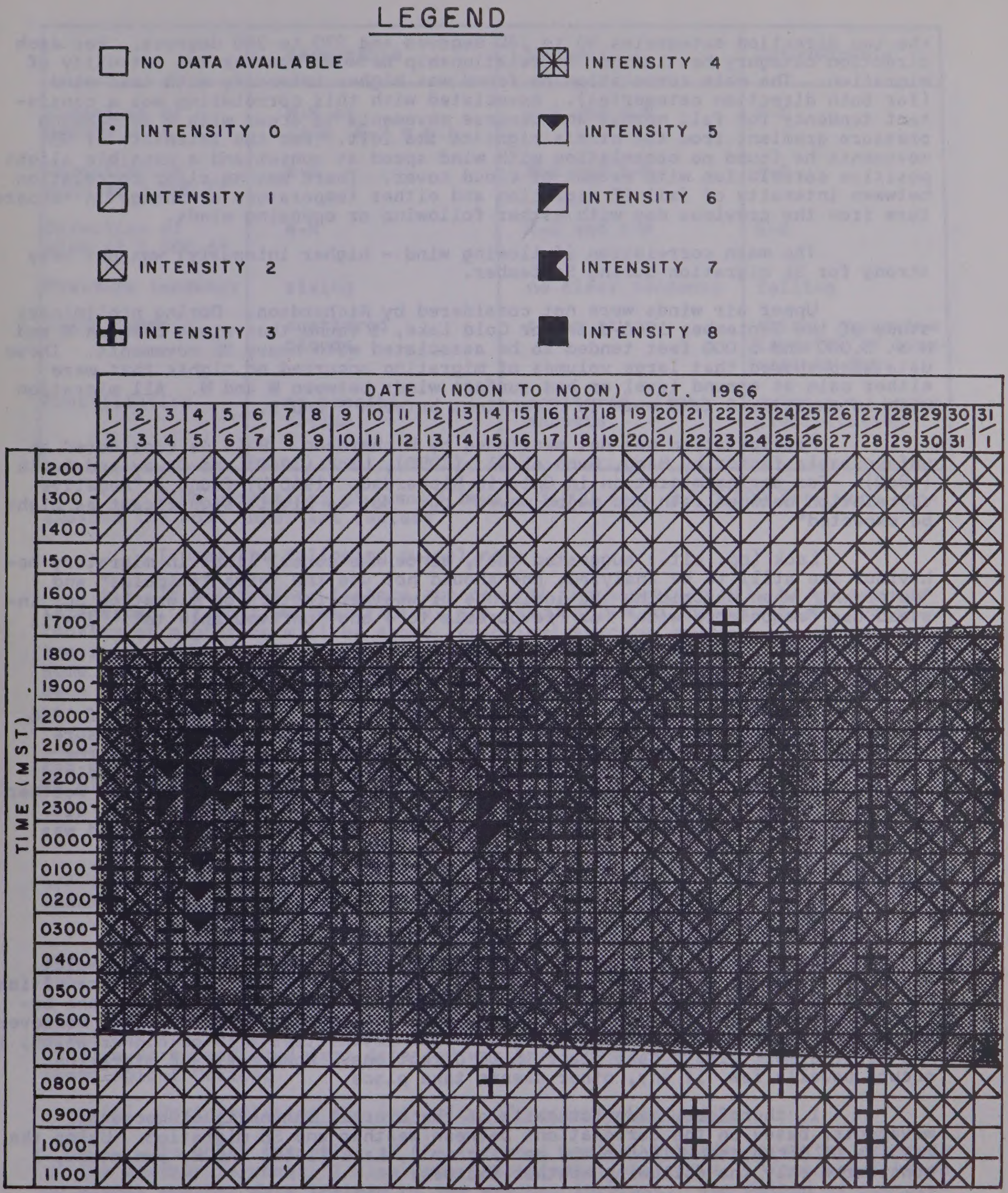


FIG. 2

HOURLY INTENSITIES OF MIGRATION OVER CFB COLD LAKE, ALBERTA, AND ITS SURROUNDING AREA (RADIUS 85 MILES) DURING OCTOBER 1966. DATA WERE OBTAINED FROM RADAR FILM, ASSESSED ACCORDING TO FRYERS' (1966) CODE. INTENSITIES WERE DETERMINED ON THE HOUR. SHADED AREA INDICATES PERIOD BETWEEN SUNSET AND SUNRISE.

the two direction categories 90 to 180 degrees and 270 to 360 degrees. For each direction category he studied the relationship between weather and intensity of migration. The main correlation he found was higher intensity with tail wind (for both direction categories). Associated with this correlation was a consistent tendency for fall normal and reverse movements to occur with a decreasing pressure gradient from the bird's right to its left. For the intensity of SE movements he found no correlation with wind speed at sunset and a possible slight positive correlation with extent of cloud cover. There was no clear correlation between intensity of fall SE migration and either temperature or change in temperature from the previous day with either following or opposing winds.

The main correlation (following wind - higher intensity) was not very strong for SE migration during September.

Upper air winds were not considered by Richardson. During preliminary study of the September 1966 data for Cold Lake, I found that winds between W and N at 3,000 and 5,000 feet tended to be associated with heavy SE movements. These data also showed that large volumes of migration occurred on nights that were either calm at ground level or had surface winds between W and N. All migration with intensities 6 to 8 were in directions between E and S.

Precipitation was not mentioned by Richardson. Rain is considered an unfavourable factor by Bagg, Gunn et al. (1950), Lack (1960) and Drury and Keith (1962). For spring migration in Ontario Richardson (1966 b) found a "negative correlation between rain and major waves" but "not as highly significant as might be expected".

Lack (op. cit.) suggested that, since the causal links in migratory behaviour are still to be analyzed, one should not use the terms "stimulus" and "deterrent" when describing the influence of weather factors on migration but instead use "associated with" (or "favourable to") and "unfavourable to". I will use Lack's terminology.

(c) Experimental migration forecasts at CFB Cold Lake

Fryers (1966) made migration forecasts in the spring and fall of 1966. He based his forecasts on (a) the fact that migrants tend to fly the pressure patterns, (b) the average intensity patterns, obtained from radar films from previous years, (c) the latest information on the stage of migration, obtained from hourly Polaroid time-exposure pictures of the PPI scope, and (d) the weather forecast. Although the accuracy of his predictions was high, Fryers (op. cit.) pointed out that a better understanding of the biological factors involved was needed.

METHODS

(a) Forecasting the intensity of nocturnal migration

Probably the best way to forecast bird migration would be to predict the intensities of the events in NW and SE directions, to add up these intensities and to express the sum in terms of the overall intensity. This was not done because there was no satisfactory method to summate intensities of events. Moreover the RCAF was interested only in movements with intensities of 5 or higher which, in the fall, almost always take place in SE directions. When heavy SE migration occurs usually few, if any, other events take place.

I, therefore, made forecasts of the overall intensity of nocturnal movements, based on the correlations between weather and SE migration. Using the results of Richardson (1966 b and pers. comm.), Lack (1960) and my own study, I considered only the following weather factors:

	Favourable	Neutral	Unfavourable
Direction of ground wind	W-N or calm (0-3 m.p.h.)	N-E and S-W	E-S
Direction of wind at 3,000 ft.	W-N	N-E and S-W	E-S
Direction of wind at 5,000 ft.	W-N	N-E and S-W	E-S
Pressure tendency	rising	no clear tendency	falling
Cloud cover	scattered clouds	clear sky	thick, extensive layer(s) of overcast or fog
Precipitation	no precipitation	scattered, light showers	extensive, heavy precipitation

Wind directions at ground level, 3,000 feet and 5,000 feet were considered the most important factors.

I used the following guidelines:

(1) If all weather factors are neutral the migration will be of average intensity. If most weather factors are favourable (or unfavourable), the intensity of migration will be above (or below) average, maximum (or minimum) intensity occurring when all weather factors are favourable (or unfavourable). If some weather factors are favourable and others unfavourable, they may "neutralize" each other in which case migration will be of average intensity.

The average intensities are given in Figure 3, in terms of overall intensity. Since overall intensities, including NW events, served as a standard for my forecast of SE migration, I more or less compensated for not considering NW migration.

Maximum and minimum intensities may be seen in Figures 1 and 2.

(2) When all or most weather factors have been unfavourable for three consecutive nights, their influence decreases; in other words the birds start to fly under unfavourable conditions in numbers greater than usual.

(3) In October, when all or most weather factors have been favourable for two or three nights, the number of migrating birds decreases on successive nights even though the favourable weather conditions continue.

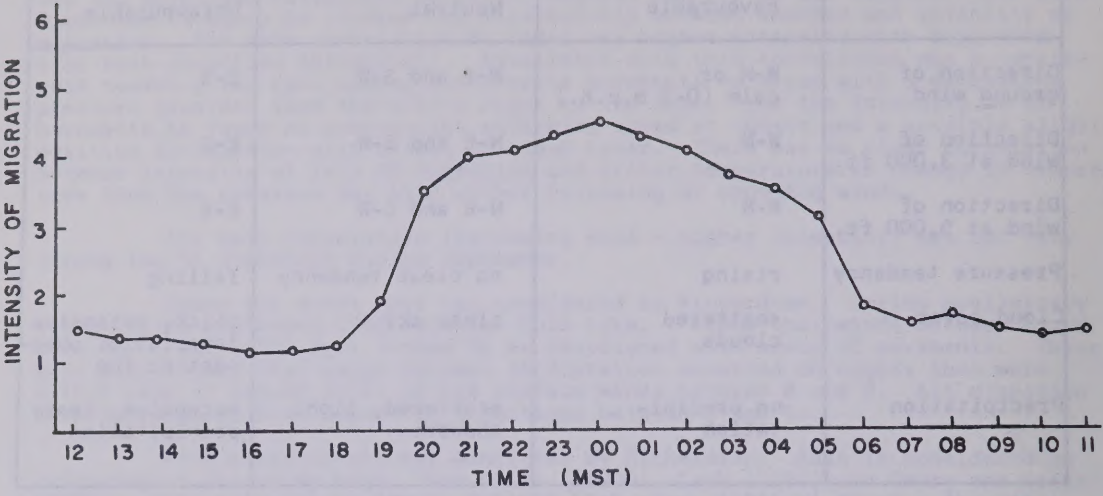
From 16 September to 16 October 1968 daily forecasts were made at 1600 hours MST for the period 1900 to 0600 hours MST. The hourly intensities of migration were predicted from detailed weather forecasts provided by the Base Meteorological Office.

(b) Postpredicting the intensity of nocturnal migration

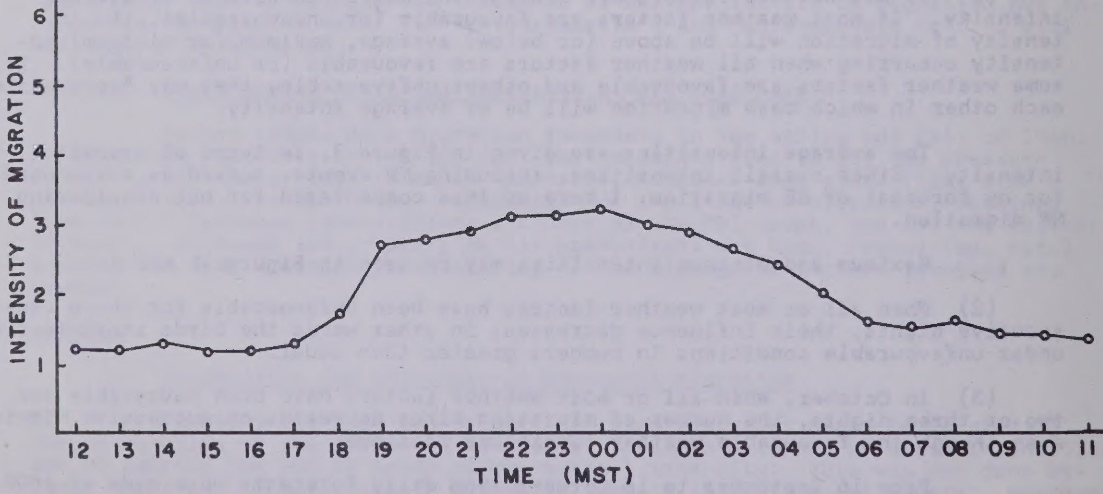
To check the value of the forecast system, regardless of the accuracy of the weather forecast, I also made "postpredictions", i.e., "forecasts" based on actual weather data instead of the weather forecast. The method of postpredicting was the same as for forecasting. The weather reports were provided by the Base Meteorological Office.

(c) Determining the accuracy of migration predictions

To check the accuracy of the predictions, films were made of the PPI scope of the 23-cm. surveillance radar near CFB Cold Lake. They were assessed on the hourly overall intensities, which were determined on the hour. A predicted *hourly* intensity was considered accurate if it did not differ from the



(a) 15 - 30 SEPTEMBER (1965, 1966, 1967)



(b) 1 - 15 OCTOBER (1965, 1966)

FIG. 3

AVERAGE HOURLY INTENSITY OF MIGRATION OVER CFB COLD LAKE, ALBERTA, AND ITS SURROUNDING AREA (RADIUS 85 MILES). DATA WERE OBTAINED FROM RADAR FILM, ASSESSED ACCORDING TO FRYERS' (1966) CODE. INTENSITIES WERE DETERMINED ON THE HOUR.

actual intensity by more than one degree. The accuracy of the weather forecast had to be taken into account since it might influence the results. The weather forecast was usually not detailed enough for determining its accuracy per hour. I, therefore, used the following categories per night:

inaccurate: when (a) the actual wind direction at ground level, at 3,000 feet or at 5,000 feet was, during most of the period for which radar data were available, in another quadrant or category of favourableness than forecast.

or (b) when extensive areas of precipitation and/or fog occurred during most of the period for which radar data were available, while no precipitation or only occasional drizzle was forecast and vice versa.

accurate: when not inaccurate

When considering the accuracy of migration predictions per night I used the following categories:

accurate: when (a) $\frac{\Sigma|\text{predicted hourly intensity - actual hourly intensity}|}{\text{number of hours with radar data}} < 1.5$

and (b) no difference between predicted and actual intensity is greater than 2 and no difference of 2 occurs more than three times in a row.

overestimate: when not accurate and when the predicted intensities were on the average higher than the actual ones.

underestimate: when not accurate and when the predicted intensities were on the average lower than the actual ones.

RESULTS

The results of the migration forecasts and postpredictions for the periods 16 September - 1 October and 1-17 October 1968 are given in Table I. This table shows that, on an hourly basis, the accuracies of the postpredictions for these two periods (77 and 92 per cent) were higher than those of the forecasts (63 and 76 per cent) and that the accuracy of both postpredictions and forecasts was higher in October (92 and 76 per cent) than in September (77 and 63 per cent).

Regarding the intensities that the RCAF was interested in, there were in total 28 hours with actual intensity of 5 or higher. Fifteen hours (54 per cent) were accurately forecast, while a high degree of inaccuracy (i.e., $|\text{actual intensity - predicted intensity}| > 2$) occurred for 6 hours (21 per cent). Twenty-two hours (79 per cent) were accurately postpredicted, while a high degree of inaccuracy occurred for one hour (4 per cent).

An intensity of 5 or higher was forecast for a total of 25 hours, and postpredicted for 29 hours. The forecasts were accurate for 15 hours (60 per cent) and had a high degree of inaccuracy for 3 hours (12 per cent). The postpredictions were accurate for 21 hours (72 per cent) and had a high degree of inaccuracy for zero hours (0 per cent).

There were in total 120 hours with actual intensity of 4 or lower. Eighty-nine hours (74 per cent) were accurately forecast, while a high degree of inaccuracy occurred for 13 hours (11 per cent). One hundred and five hours (88 per cent) were accurately postpredicted, while a high degree of inaccuracy occurred for zero hours (0 per cent).

An intensity of 4 or lower was forecast for a total of 123 hours, and postpredicted for 119 hours. The forecasts were accurate for 89 hours (72 per cent) and had a high degree of inaccuracy for 16 hours (13 per cent). The postpredictions were accurate for 106 hours (89 per cent) and had a high degree of inaccuracy for 2 hours (2 per cent).

To check whether the lower accuracy of the forecasts was due to inaccuracies of the weather forecasts, a further analysis was made for the six nights with at least one actual hourly intensity of 5 or higher. The accuracy

Table 1 Frequency of differences between forecast and actual hourly intensities of migration and, in parentheses, of differences between postpredicted and actual hourly intensities. CFB Cold Lake, Alberta. A prediction is deemed accurate if it differs by less than 2 degrees from the actual intensity. A: 16 Sept - 1 Oct 1968 (62 hours with radar data). B: 1-17 Oct 1968(86 hours with radar data).

A

		Difference between the forecast and actual hourly intensity (left column) and that between the postpredicted and actual hourly intensity (right column).										Accurate predictions
		-5	-4	-3	-2	-1	0	+1	+2	+3	+4	(%)
Actual hourly intensity	0	- -	- -	- -	- -	- -	- -	6 (6)	- (1)	1 -	- -	86 (86)
	1	- -	- -	- -	- -	3 -	2 (7)	1 (5)	1 (2)	4 -	3 -	43 (86)
	2	- -	- -	- -	- -	- (1)	2 (2)	1 -	1 (1)	- -	- -	75 (75)
	3	- -	- -	- -	1 -	1 -	1 (1)	2 (2)	- (2)	- -	- -	80 (60)
	4	- -	- -	- -	- (1)	2 (1)	2 (1)	1 (2)	1 (1)	- -	- -	83 (67)
	5	- -	- -	- -	- (1)	2 (4)	5 (2)	1 (2)	3 (2)	- -	- -	73 (73)
	6	1 -	2 (1)	- -	- (1)	3 (3)	2 (2)	1 (2)	- -	- -	- -	67 (78)
	7	1 -	- -	2 -	2 (1)	1 (2)	- (2)	- (1)	- -	- -	- -	17 (83)
	8	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
Totals	numbers	2	2 (1)	2	3 (4)	12 (11)	14 (17)	13 (20)	6 (9)	5	3	62 (62)
	percent	3	3 (2)	3	5 (6)	19 (18)	23 (27)	21 (32)	10 (15)	8	5	100 (100)
	percent per group	14% (8%)				63% (77%)			23% (15%)			100 (100)

B

		-5	-4	-3	-2	-1	0	+1	+2	+3	+4	
Actual hourly intensity	0	- -	- -	- -	- -	- -	- -	- (1)	- (1)	1 -	1 -	0 (50)
	1	- -	- -	- -	- -	1 (4)	10 (22)	16 (8)	4 -	3 -	- -	79 (100)
	2	- -	- -	- -	1 (1)	4 (5)	15 (12)	7 (12)	4 (1)	- -	- -	84 (94)
	3	- -	- -	- (1)	4 (1)	1 (2)	7 (6)	1 (3)	- -	- -	- -	69 (84)
	4	- -	- -	- -	- -	- (1)	2 -	1 (1)	1 (2)	- -	- -	75 (50)
	5	- -	- -	- -	1 -	- -	- (1)	- -	- -	- -	- -	0 (100)
	6	- -	- -	- -	1 -	- (1)	- -	- -	- -	- -	- -	0 (100)
	7	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
	8	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
Totals	numbers			(1)	7 (2)	6 (13)	34 (41)	25 (25)	9 (4)	4	1	86 (86)
	percent			(1)	8 (2)	7 (15)	40 (48)	29 (29)	10 (5)	5	1	100 (100)
	percent per group	8% (3%)				76% (92%)			16% (5%)			100 (100)

of the migration predictions and weather forecast per night (see Methods) is given in Table 2. This table also gives a possible explanation in case of an inaccurate prediction. Table 2 shows that 3 (50 per cent) and 4 (67 per cent) of the six nights were accurately forecast and postpredicted, respectively. The forecast would have been accurate on 27-28 September if the weather forecast had been accurate and on 25-26 September if the guidelines had been used correctly. On 23-24 September the postprediction would have been accurate if the intensity at 1900 hours MST had been 3 or 4 rather than 6, which is very unusual (see Fig. 1). The forecast for that night would have been accurate if there had been a normal situation and if the guidelines had been used correctly.

DISCUSSION

Method

To make the migration forecast method as simple as possible all species were lumped together and only a few factors of the local weather were used.

When making the forecasts the average intensity curve with overall intensities, which included NW movements, was used but the weather factors were considered only with respect to SE migration. This is satisfactory for high-intensity nights when almost all migration is SE. During low-intensity nights there may have been NW movements, which were not considered. In these cases the use of the average intensity curve caused an overestimate of intensities of SE movements but it also produced a better approximation of the overall intensity.

The arithmetical averaging of hourly intensities, as done in Figure 3, is a possible source of error. At the time that the migration forecasts were made, I had some indication from moon-watch data that the relationship between the steps of the 0-8 intensity scale might be linear (Blokpoel, 1967).

The migration forecast method is based on a few known correlations between intensity of bird migration and certain weather factors, e.g. wind direction and precipitation. These correlations are only qualitative, but the predictions had to be exact (no deviation greater than plus or minus one from the actual intensities).

Since it was unknown how much each weather factor contributed to a certain intensity, and since the main correlations did not hold very well for September, the forecasting of migration was an art rather than a science.

Results

Two inaccurate forecasts (Table 2) could be explained, at least partly, as a result of incorrect use of the prediction guidelines. The forecasts often had to be made in a hurry. The postpredictions were made later, with more deliberation but without knowing the actual intensities. I have no explanation for the inaccurate postprediction for 17-18 September.

Considering errors of plus or minus one degree as insignificant, Fryers' (1966) accuracy for September was 71 per cent (mine 63 per cent). For actual hourly intensities of 5 and higher in September these figures were 34 per cent and 58 per cent, respectively. This comparison is seriously weakened by the lack of data for many nights, which makes my results suggestive only.

According to Lowery and Newman (1966) it is doubtful whether the intensity of bird migration can be completely explained by the weather, since they found for 1-5 October 1952 that "Meteorologically similar continental situations on the opening and closing nights of the study with contrasting migration results point to the danger of attempting to predict ornithological results from weather alone".

Yet, analysis of my few data suggests that for the period mid-September to mid-October the majority of nights with heavy migration might well be accurately forecast. In the fall of 1969 we will make daily forecasts of the intensity of nocturnal migration for the Cold Lake area. The forecasts will be presented at the briefings for night flying.

TABLE 2 ACCURACY OF WEATHER FORECAST, MIGRATION FORECAST AND POSTPREDICTION FOR ALL SIX NIGHTS WITH AT LEAST ONE HOURLY INTENSITY OF 5 OR HIGHER. See text for criteria. 16 Sept. - 17 Oct., 1968. CFB Cold Lake, Alberta. Acc = accurate, inacc = inaccurate, overest = overestimate and underest = underestimate.

Date 1968	Number of hours with radar data	Extremes of actual hourly intensities	Accuracy			Possible explanation of inaccuracy	
			Weather forecast	Migration forecast	Migration postprediction	Migration forecast	Migration postprediction
16-17 Sept.	5	2-6	acc	acc	acc	-	-
17-18 Sept.	7	2-5	acc	acc	overest	-	no explanation
23-24 Sept.	6	6-7	acc	underest	underest	incorrect use of guidelines and unusual situation	unusual situation (see text)
25-26 Sept.	11	3-7	acc	underest	acc	incorrect use of guidelines	-
27-28 Sept.	11	2-5	inacc	overest	acc	inaccurate weather forecast	-
4-5 Oct.	4	2-6	acc	acc	acc	-	-

ACKNOWLEDGEMENTS

I am thankful to Lt. Col. E.K. Fallis, Commanding Officer of 448 Squadron, Mr. W.R. Fryers, Project Officer Meteorology of 448 Squadron, Col. W.H. Vincent, Commanding Officer of CFB Cold Lake, Mr. C.R. Finlay, Base Meteorological Officer, and Maj. R.K. Wolff, Commanding Officer of 42 Radar Squadron, for their support.

My special thanks go to Cpl. P.P. Defosses, for assessing the radar films and compiling the data for the figures. Dr. J.B. Gollop, Canadian Wildlife Service, read the draft of this paper. I am very grateful for his numerous comments and suggestions.

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DISCUSSION

Nisbet:	In calculating figures for migration traffic rates, did you use any figure for flock size?
Blokpoel:	No, I did not. I considered one birdspike as representing one bird. The calculated Migration Traffic Rates are therefore minimum estimates. During moonwatch observations we saw that the great majority of the birds were flying singly across the moon's surface. This would indicate that most migrants flew either singly or in very loose groups, with a great distance between the birds. Since the radar beam is about 4.5x as wide as the angle of vision of the moonwatcher, it is possible, especially at greater heights, that the radar showed such a loose group as a single rather than several bird echoes.
Nisbet:	I find it a little difficult to evaluate the measure which you use for percentage agreement with prediction. Did you calculate an actual correlation coefficient of observed with predicted migration density?

Blokpoel: No, I did not. I considered a predicted hourly intensity as "accurate" when it did not differ more than plus or minus one category from the actual intensity. The percentage of agreement is the number of "accurate" predictions expressed as a percentage of the total number of hourly predictions.

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